MEMORANDUM

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TO: Damien Houlihan (EPA Region I) and Jennifer Chan (EPA Headquarters)

FROM: John Sunda and Kelly Meadows

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SUBJECT: Engineering Analysis of Adding a Submerged Offshore Intake at Pilgrim Station

Tetra Tech was tasked by EPA Region I with assessing the possibility of retrofitting the Pilgrim Nuclear Power Station (PNPS) with a submerged offshore intake that may incorporate either velocity caps or wedgewire screens. Items to be addressed in this memo include the technology feasibility, operational and design concerns as they relate to nuclear safety issues, cost, and estimated percent reduction of impingement mortality and entrainment. This is a companion memo to the memo titled “Pilgrim Station Cooling Water Intake Location Analysis,” also provided today.

Technical Feasibility of an Offshore Intake Design

There are two general methods for constructing offshore intakes: one is to place pipes in trenches along the ocean bottom and cover them with backfill, while the second is to construct tunnels beneath the ocean floor connected to shafts or risers at either end. Given the site-specific conditions of a potentially rocky bottom and substantial differences in benthic impacts (as discussed below), the most plausible design and construction method for installation of a submerged offshore intake at PNPS is the use of shafts and tunnels using construction methods similar to those used at Seabrook and Oak Creek. This method substantially reduces the impact to benthic community by minimizing the disturbance of the ocean floor and presents a much more robust design that would be much less susceptible to various failure scenarios (e.g., wave action).

The minimum depth required to avoid impact on navigation is approximately 10 meters with the closest distance offshore being about 2,800 ft. A depth of 15 meters is considered as more practical minimum target depth in order to provide greater protection from influences of tidal range and wave action. At these depths, the corresponding distance offshore is significant; as discussed below, an important element in cleaning a wedgewire screen is the airburst system. Without that system, wedgewire screens (either coarse or fine mesh) become less feasible.

A depth range of 30 to 40 meters was considered as the practical limit for the deepest intake depth, given the limitations on diver capabilities in deeper water and the fact that depths greater than 40 m are associated with offshore distances of greater than 30,000 ft. For this analysis, a distance of 20,000 ft. was considered as the practical offshore distance limit since the seafloor depth contour tends to level off at greater distances. Additionally, the nearby Seabrook facility uses an offshore intake at a distance of approximately 17,000 feet from the facility. Since other similar configurations are at shorter distances offshore, 20,000 feet was selected as the maximum distance for this analysis.

Regardless of which offshore technology is selected, the design of the submerged intake conduit and shoreline structure component does not vary significantly.

<u>Example Designs for Offshore Intakes Including Wedgewire Systems</u>

Seabrook Nuclear Power Station

The Seabrook Nuclear Power Station is a nuclear plant where use of submerged offshore ocean intake with velocity caps is demonstrated and is located in relatively close proximity to PNPS (about 65 miles to the north). The dual 19 ft. diameter 17,000 ft. long intake tunnels at Seabrook were constructed using a hard rock tunneling method where shafts and a sloping horizontal tunnel were excavated. The original design was for two reactors with a total cooling flow of twice the existing reactor design flow of 684 mgd (475,000 gpm). The intake includes a velocity cap, the top of which is located 18 ft. below the surface in water that is approximately 60 ft. deep. The intake tunnel slopes from a depth of 160 ft. at the intake to 230 ft. at the shaft connecting to the facility.

San Onofre Nuclear Power Station

The San Onofre Nuclear Generating Station (SONGS) is a nuclear plant where use of submerged offshore ocean intake with velocity caps is demonstrated. SONGS also conducted a preliminary study that explored a potential retrofit of the primary intake with wedgewire screens, concluding it is technically feasible (Bechtel 2012). At SONGS, the existing primary offshore intake structure (POIS) is located 3,200 ft. offshore in water that is 32 ft. deep and utilizes a velocity cap. A smaller auxiliary offshore intake structure (AOIS) with a velocity cap that serves as part of the emergency cooling water system and is designed to withstand seismic loading is located about 92 ft. shoreward of the POIS. The smaller AOIS operates in parallel with POIS and under normal conditions provides 3% of the cooling water flow. Should the POIS fail, the AOIS is capable of supplying the entire capacity of the service water cooling system (4% of total cooling water). The top of the AOIS is 20 ft. below the surface and extends above the ocean floor by an 11.5 ft. riser with an inner diameter of 4 ft. The AOIS velocity cap is 9.5 ft. in diameter with four openings that are 30 inch wide by 17 inches tall (CSWRCB 2013). The preliminary design of the proposed project to add wedgewire screens to the POIS does not include modifications to the AOIS and, should the wedgewire screens become clogged or fail in some other manner, the AOIS is available. Additionally, it was SCE's position that the AOIS should be excluded for safety reasons from recent plans to add large organism exclusion devices (essentially 9 in spaced bars) to the intake velocity caps (CSWRCB 2013). The concern was that the AOIS is susceptible to plugging by kelp, particularly kelp "snowballs" that can develop when kelp plants are dislodged during wave events. Because the existing intake already includes the offshore tunnel, the addition of the wedgewire screens was not expected to increase the intake head loss enough to affect the cooling water pump submergence enough to require changes to the exiting cooling water pumping system.

Oak Creek Power Plant

An intake design configuration that could serve as a model for retrofitting an offshore intake at PNPS is the Oak Creek expansion project located on the western shore of Lake Michigan that was recently completed in 2010. In this project, an existing shoreline intake was modified by placing a concrete dike wall across the intake channel in front of the intake. The dike wall includes gates that can be manually opened to allow the intake to operate in two different modes. With the gates open, the intake can withdraw the full capacity of water at the shoreline through its existing intake. With the gates closed, the intake withdraws the full capacity through the newly installed submerged offshore intake. The existing traveling screens are kept in place but are only needed during shoreline intake operating mode. During construction, a sheet pile was installed to isolate the construction area so that operation of the existing plant could continue uninterrupted. A shaft was excavated behind the sheet pile wall to a depth of 130 ft. below the lake bed and then a horizontal shaft 26 ft. in diameter was excavated a total distance of 9,200 ft. The intake itself is located about 6,000 ft. offshore with the difference consisting of the tunnel connection to the new generating units being constructed adjacent to the existing plant. At the offshore terminus four 12 ft. diameter vertical shafts connect to twenty four (six per shaft) 3/8 inch mesh, CuNi, eight ft. diameter wedgewire screens.

The area in which the intake is located has relatively low debris loads and the screens are generally cleaned by divers once per year. The Oak Creek wedgewire screens do not use an air backwash system due to the distance from shore and removal of any accumulated debris is performed periodically by divers. If the wedgewire screens unexpectedly become plugged, the gates within the dike wall can be opened to provide an alternate source of water until the screens can be cleaned. The facility has only had such problems with frazil in the winter (We-energies

2014a). Sometimes during periods with high winds and extreme low temperatures frazil ice[1] will form in the super-cooled water on the screen surfaces. This is detected by a significant drop in the low-head pump basin water elevation at which point the dike wall gates are opened completely and the plant operates in shoreline intake mode until the weather/water temperature conditions improve and the ice melts.

The total cost for the dike walls, intake forebay, intake tunnel and shafts and the intake screens was $121 million (We-engeries 2014b). The capacity of this intake which serves the existing 1,135 MW power plant plus the new Elm Road Generating Station that has two 615 MW units is 2,200 mgd or nearly five times that of PNPS. The flow capacity of the existing plant which employs the lift pumps is 820,000 gpm (1,181 mgd).

Screen Backwash and Wedgewire Screen Mesh Size

The reduction in impingement mortality using coarse mesh (3/8 in.) wedgewire screens located far offshore is expected to be substantial, with data from some studies showing reductions in impingement of near 100 percent. In order to ensure complete exclusion of fish eggs and larvae (i.e., to also reduce entrainment), the mesh size must be in the order of 1-2 mm or smaller. However, use of finer mesh would result in a potentially large increase in the rate and frequency of plugging of the intake screens with debris and, as discussed below, options for cleaning debris off of the submerged intake screens are limited.

An air backwash screen cleaning system is typically used to remove accumulated debris at intakes close to the shore. However, in general, wedgewire screen air backwash systems are not economically practical for intakes that are greater than about 1,000 ft. from the shore. One reason is that the accumulator (a component of the airburst system) must be designed with a volume of 2 to 3 times the combined volume of the screen and the air supply pipe; the volume associated with a very long air supply pipe would require an extremely large accumulator and compressed air volumes. Another reason is that the typical design includes a separate air supply pipe for each screen, which can be costly. Another impediment is that the installation of the air supply pipes present additional engineering challenges for a deep tunnel intake design since the air supply pipes would need to run parallel to the tunnel either along the ocean bottom or most likely within the tunnel structure. Given that the minimum offshore distances being considered for PNPS are several thousand feet or more, an air backwash system is not considered to be economically feasible for use with a wedgewire screen intake system at PNPS. Water backwashes can be employed but the force is much diminished compared to the air backwash and the uneven distribution of flow across the screens further limits the effectiveness. Also, the design of an

[1] See the following link for a video taken by a diver of frazil ice on wedgewire screens in water 25 ft. deep at the Manitowac Power plant located about 85 miles to the north of Oak Creek: https://www.youtube.com/watch?v=COMV3UEE47A

effective water backwash presents additional engineering challenges. Thus, periodic cleaning by divers (as is employed at Oak Creek) is the most practical method available.

Clearly the debris loading for finer mesh screens could be problematic and thus fine mesh wedgewire screens are likely not feasible at PNPS. It is not clear what the degree and frequency of debris loading would be for coarse mesh wedgewire screens at the locations considered for PNPS. The discussion of impingement at Seabrook makes reference to episodic events that seem to be associated with fall and winter storms, which presumably could include an associated significant increase in debris loading as well.

Benthic Area Impacted

An intake conduit design velocity of 6 fps is considered as a reasonable optimum value. Based on this velocity and a total pump capacity of 324,500 gpm, a single circular conduit would need to have an inner diameter of 12 ft. If two conduits are used (e.g., as risers on the intake end) circular conduits would need to have an inner diameter of 9 ft. Two intake riser shafts at the intake end are assumed for this preliminary design. Note that the area estimates below are preliminary estimates intended for comparison of the order of magnitude of the relative impacts.

A submerged intake pipe construction method that involved excavating, laying, and covering the intake pipe on the ocean bottom for any significant distance would require considerable disturbance of the existing benthic community. For example, a trench for a 12 ft. diameter pipe would disturb an area of 50 ft. or more wide and even the minimum length of around 2,800 ft. would require the disturbance of up to an estimated 140,000 sq. ft. of benthic habitat. As discussed below a tunnel and shaft method would impact a much smaller area.

The following discussion is based on using the shaft and deep tunnel design employed at both Seabrook and Oak Creek. The intake dike wall, low lift pump station and intake shaft would all be constructed within the confined of the existing intake cove and would only affect areas within the existing intake cove which has been dredged previously and therefore the shore-based end of the system would affect only previously disturbed areas.

Assuming that two 9 ft. diameter risers are employed at the intake end, the benthic area disturbed would include the risers and rock placed around them and affect an area of up to 25 ft. in diameter or a total estimated area of up to 1,000 sq. ft.

If wedgewire screens are used, each screen would be placed up to 30 ft. apart and the pipe header excavation and support may affect an area of up to 25 ft. Assuming eight screens are employed the estimated affected area would be a total of up to 7,000 sq. ft.

Offshore Intake Nuclear Safety Concerns

Within the cooling water intake system at PNPS, the salt service water (SSW) pumps and the intake components that supply water to the SSW pumps are designated as a safety-related system and the design must be approved by the NRC to operate in all conditions. The cooling system and intake flow requirements for the steam condensers are not safety-related, since they are not needed to maintain the reactor core cooling system when the generating units are shut down. At PNPS there are 5 SSW pumps that have a total flow capacity of 13,500 gpm, which is 4% of the total design intake flow rate of 324,500. Important safety-related issues regarding the conversion from a shoreline intake to a submerged offshore intake are: 1) the reliability of the intake system to be capable of supplying water to the SSW pumps under adverse conditions, 2) the ability of the system to keep the water elevation at the pumps from dropping below the required pump submergence elevation which prevents damage to the SSW pumps caused by cavitation, and 3) concerns regarding significant excavation near the reactor

At SONGS, the intake system reliability requirement is addressed by including the AOIS described above. This smaller intake was designed to serve as a sole backup source for service water if the POIS were to fail. Maintaining sufficient pump submergence during plant operation for the proposed addition of wedgewire screen at the existing offshore intake inlet at SONGS was not a significant problem because much of the head loss through submerged offshore intakes is associated with the frictional losses within the long intake pipe which would not change. The only additional losses would be through the new screen piping and the screens themselves which could be designed using pipe diameters and inlet velocities that would minimize any increase.

If an intake system design similar to Oak Creek were employed at PNPS, the additional gates in the dike wall would provide the option of alternating between shoreline and offshore mode. The ability to bypass the submerged intake during emergency conditions provides a similar degree of safety as the existing intake configuration. If deemed necessary, a passive continuously open small gate could be placed within the dike wall to provide an emergency source of service water without relying upon the need to physically open a gate.

The Oak Creek design configuration however, does not ensure sufficient pump submergence during plant operation under low tide conditions. At Oak Creek, the increased head loss associated with the new intake system is compensated for using a low-head lift pump station constructed between the intake tunnel shaft outlet basin and the area between the dike wall and the existing intake. This eliminates the need to modify the existing cooling system equipment and allows for continued use of the existing intake during construction. The number of lift pumps matches that of the cooling water pumps and have a slightly higher capacity with excess flow spilling over a weir back into the inlet basin for the lift pumps. Thus, the Oak Creek design configuration would adequately address the nuclear safety issues of an offshore intake at PNPS by providing an alternate source of service water during emergency conditions and by providing sufficient pump submergence during normal operations using low-head lift pumps.

Another safety concern associated with implementing the Oak Creek design at PNPS is that, at Oak Creek, the intake shaft was constructed using the drilling and blasting method. Because of the potential effect of the blasting shock waves on the safety and integrity of the reactor equipment, an alternative method of mechanical shaft boring can be employed instead.

Technology Costs

Capital Costs

Enercon cited an estimated capital cost of $36.4 million dollars (2007 dollars) for an intake submerged 2,800 ft. offshore based upon an estimate of $16.2 million in 1980 dollars adjusted for inflation cited in the “Pilgrim Station Unit 2: Applicants Environmental Report” developed during the original licensing of the plant. Adjusted for inflation, this estimate becomes $45 million in 2014 dollars using the ENR CCI. No details are provided concerning system design but this was for an alternative in a new system, so it is reasonable to assume that this only includes the net increase for the intake conduit and inlet technology and that retrofit costs including intake structure and pump system modifications are not included.

For Oak Creek, more recent actual contract costs for the intake dike wall, intake tunnel, wedgewire screens, and low-head lift pump system at Oak Creek are available. The actual cost of $121 million in 2009 dollars (We-energies 2014b) provides a good starting point for estimating submerged offshore intake costs since it is more recent and includes necessary retrofit components. This value can be adjusted differences between PNPS and Oak Creek using a regional construction cost difference of 12%,[2] a contingency/allowance factor of 30% to account for differences in plant and waterbody type (nuclear vs. coal and saltwater ocean vs. freshwater Great Lake), and a 2014 inflation factor of 15% based on ENR CCI. Applying these factors result in a comparable costs of $202 million for a project at PNPS of similar size to Oak Creek. Of this $202 million, 20% ($40 million) is assumed to be the same for both projects. This accounts for less scalable components such as the intake channel modifications (e.g., dike walls, sheet piling, etc.) engineering, and mobilization/demobilization. For the purposes of estimating costs, the remaining costs are divided into components to account for differences in design flow and tunnel length since the intake serves both the Oak Creek Power Plant and the Elm Road Generating Station. The remaining costs are divided into combined intake (surface water intake system and gates), tunnel, and the low lift pump system and electrical/controls. The cost must be adjusted downward to account for the fact that the combined intake at Oak Creek is designed for a total flow volume of 2,246 mgd or 4.8 times larger than the 467 mgd design capacity at PNPS. Also the low-head lift pump component including electrical and controls that serves Oak Creek only is designed for 1,182 mgd which is 2.5 times larger than the design capacity at PNPS. The combined intake and tunnel components for Oak Creek are scaled to account for the smaller flow

[2] Based on ratio of state average regional factors for Massachusetts versus Wisconsin from the EPA 316(b) existing facility cost tool.

volume at PNPS using a factor of 3.5.[3] The tunnel component is further scaled in a linear manner to account for the different offshore distances. The low head lift pump system component is scaled using a factor of 2.5. Also, to account for differences in the costs for the option of using velocity caps versus wedgewire screens, the total estimated tunnel costs are reduced by $6 million if velocity caps are employed instead of wedgewire screens. Table 1 presents a summary of the capital costs for adding a submerged intake similar in concept to the design used at Oak Creek for selected tunnel lengths and intake technologies. Note that the estimated costs of $56 million for an intake with a velocity cap at 2,800 ft. offshore is similar in magnitude to the $45 million adjusted costs from the Enercon new facility net cost estimate if a 25% factor is added to account for the intake modifications and low-head pumps. Also, the distance of 7,000 ft corresponds to the distance to the potentially desirable area shown in Figure 12 of the companion memo.

Table 1. Estimated Capital and O&M Costs for Adding a Submerged Offshore Intake at PNPS with Velocity Caps and Wedgewire Screens

Distance Offshore (Feet)	Offshore Intake With Velocity Cap	Offshore Intake With Wedgewire Screens	Velocity Cap		Wedgewire	
	Capital Costs	Capital Costs	O&M Low	O&M High	O&M Low	O&M High
2,800	$56,000,000	$62,000,000	$142,000	$277,000	$175,000	$350,000
7,000	$70,000,000	$76,000,000	$197,000	$387,000	$230,000	$460,000
10,000	$81,000,000	$87,000,000	$253,000	$498,000	$293,000	$586,000
20,000	$115,000,000	$121,000,000	$346,000	$681,000	$399,000	$798,000

O&M Costs

Major O&M costs for a submerged offshore intake will include power consumption of the low-head pumps and periodic inspection and cleaning of the intake by divers. Head loss through the intake is a function of the intake system design varying with conduit size, length and number of screens. Table 2 presents design values and component costs for O&M. The maximum electrical power costs estimated for the low-head pumps is based on the total design flow plus 5% excess capacity (340,725 gpm), the estimated increased head loss through the new intake, a pump efficiency of 75%, and a market power costs of $65/MW. However, because the source water is tidal, the actual required pumping head needed to maintain the required pump submersion depth for the existing pumps will vary. Tidal differences between low and high tide are about 9-10 ft.

[3] To account for economies of scale, costs are assumed to have an exponential rather than linear relationship with flow. The factor of 3.5 assumes that as flow increases the costs increase by an exponential factor of 0.8 ($4.8^{0.8}$ = 3.5). Thus rather than divide by 4.8, the flow scalable costs are divided by 3.5.

in Cape Cod Bay and presuming the existing intakes were designed to operate at low tide, the intake pumping head needed to maintain sufficient depth will vary not be necessary for significant portion of the tidal range. While the design of the low-head pump system is beyond the scope of this analysis, it is conceivable that a design could be developed that varied pump energy requirements to maintain a target operating water elevation for the existing intake pumps of up to several feet above low tide which would provide a sufficient safety margin and would still allow for a substantial reduction in the pumping energy requirements of the low-head pumps during the high tide period. As such, the low end of the range of O&M costs assumes that the average pumping energy requirement is assumed to be half of the maximum.

Table 2. O&M Design and Component Costs

Distance Offshore (Feet)	Depth	Estimated Head Loss	O&M Pumping Low	O&M Pumping Maximum	Dive Inspection / event	Dive Cleaning / event	Cleaning Frequency Low	Cleaning Frequency High
	Meters	Feet	Dollars	Dollars	Dollars	Dollars	#/year	#/year
2,800	10	5	$135,000	$270,000	$7,000	$20,000	2	4
7,000	15	7	$190,000	$380,000	$7,000	$20,000	2	4
10,000	20	9	$245,000	$490,000	$8,000	$24,000	2	4
20,000	35	12	$335,000	$670,000	$11,000	$32,000	2	4

Diver costs per event are assumed to range from $7,000 to $11,000 for an inspection/cleaning of a velocity caps and from $20,000 to $32,000 for cleaning of the eight wedgewire screens. Frequency of inspection/cleaning is assumed to be annually for velocity caps. For wedgewire screens the frequency of cleaning by divers is assumed to be 2 to 4 times per year, with 2 used in the Table 1 low O&M estimate and 4 used in the high O&M estimate. Note that the actual frequency of cleaning of wedgewire screens will be based on site-specific conditions at the intake location in combination with the selected screen slot size. The range of estimated annual O&M costs for an offshore intake with velocity caps and wedgewire screens is presented in Table 1.

Estimated Impingement Mortality and Entrainment Reductions

As described in the companion memo, specific data concerning densities of impingeable and entrainable organisms at different locations and depths in the vicinity of PNPS were very limited. With no location-specific biological data at a proposed location to provide a point of comparison, it is difficult to make highly quantitative conclusions about reductions in impingement and entrainment. As a result, the analysis must rely on more generalized methods, such as comparisons to other, known data points.

The reduction estimates discussed here are those for the offshore intake structure and do not address any backup intake systems. Impingement mortality controls may not be required for the emergency flow component of the SSW system, which comprises less than 4% of the total cooling water flow. Reduction technologies may or may not be included for this component depending on selected design configuration.

Impingement Mortality

EPA has found that typical impingement mortality reductions for submerged offshore intakes with velocity caps in ocean applications can range from 50% to 97%. There was insufficient data available for a detailed assessment of impingement mortality at the various locations and distances offshore, but adequate performance data for velocity caps is available to suggest that similar performance can be expected. In their own technology analyses (Normandeau Associates 2006), the relatively nearby Seabrook plant compared its performance data to Pilgrim (i.e., compared Seabrook's velocity cap to Pilgrim's shoreline intake as an evaluation of the "calculation baseline") and concluded that the impingement reduction for a velocity cap located mid depth in 60 ft. (18 m) water was estimated to be 76% (ENERCON 2006).

Impingement mortality reductions for coarse mesh wedgewire screens are well-studied and should be close to 100%. Comparable values can be expected for PNPS and may vary slightly with water depth.

Entrainment

In their 2008 §308 Response, Enercon estimated that, based on adult equivalents, entrainment mortality comprises 99.3% of impingement and entrainment mortality combined and that the period of March through June comprises 80% of entrainment mortality (Enercon 2008).

Seabrook estimated a reduction in entrainment of 50% for the submerged intake compared to the shoreline intake at PNPS based on average ichthyoplankton density (Normandeau 2006). Another study compared the annual entrainment estimates for equivalent adult winter flounder for Seabrook and PNPS and found the difference for 1990, 1991, 1992, 1993, and 1995 ranged from 27% to 84% with an average of 70% (Saila et al 1997- Table 11).

In general, the performance in reducing entrainment between a velocity cap and coarse mesh wedgewire screens is roughly equivalent, as both rely upon intake location (i.e., depth, etc.) as the primary factor in reducing the density of entrainable organisms.

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